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INNOVATION

SPECIAL EDITION

NASA Seeks Partnership with Sensor Industry

The NASA Sensor Initiative
Satellite Sensors Find Fish and Food
Wafer "Wiggle" Going Places

NASA

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INNOVATION

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Chief Editor's Note:
Due to unforeseen circumstances in the production of *Aerospace Technology Innovation*, the March/April 2001 issue has been omitted. We apologize for any inconvenience.

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About the Cover:
NASA-sponsored sensors research is a focused initiative designed to increase NASA partnerships with companies in the sensors industry. NASA conducts sensors research in several fields, including high-temperature pressure sensors, gaseous hydrogen fiber sensors, micro-electromechanical sensors, silicon pressure sensors and gas chromatograph mass spectrometers.

Online Edition: Go to **http://nctn.hq.nasa.gov** on the World Wide Web for current and past issues.

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COMMERCIAL DEVELOPMENT MISSION UPDATE

Date*	Flight	Payload	Sponsor/Coordinator
11/01	STS-108 ISS Flight "UF-1"	Advanced ASTROCULTURE™ Zeolite Crystal Growth (ZCG) Microencapsulation Electrostatic Processing System (MEPS) Commercial Biomedical Testing Module (CBTM)	Wisconsin Center for Space Automation and Robotics Center for Advanced Microgravity Materials Processing Center for Space Power BioServe Space Technologies

* As of May 2001.

WELCOME TO INNOVATION

The NASA Sensors Initiative

By Larry Viterna
Chief, Commercial Technology Office
NASA Glenn Research Center

IT MAY SOUND LIKE A CLICHÉ, BUT SENSORS ARE the future and the future is now! This fact has not gone unnoticed by the NASA Commercial Technology Program's Marketing Team, who developed and wrote the agency's marketing plan. One of the team's recommendations was to create industry-focused initiatives, and to emphasize much of the marketing efforts on strategic sector partnerships by facilitating participation of all NASA centers. This concentration is on industry sectors that work with NASA core capabilities and investment areas. The marketing team has agreed to deliver companies and negotiate partnerships that will add industry dollars to NASA research funding. A stronger base of industry proposers for NASA solicitations is to be established, and one important focus area is geared towards the sensors industry.

Why Sensors?

A market assessment was performed to determine the needs of industry in the sensors areas and to study the overall trends. It was found that 75 percent of sensors are made in the United States. In the instrumentation industry, growth is reportedly 13.5 percent per year, with sales of approximately $49 billion in 2000. The industry employs 150,000 people worldwide. Sales in the sensors segment amount to $24 billion a year, with a 15 percent growth rate. The U.S. sensors industry employs 80,000 people.

NASA's Technology Needs

NASA, in turn, has identified technology needs of its own. It is anticipated that these needs can be met via industry partnerships and cooperative research, as well as development efforts with U.S. corporations and academia. Several of the identified needs are for low-speed gas velocity sensors, multifunctional chemical sensors, temperature and pressure sensors for harsh environments, embedded fiber Bragg sensors, NO_X sensors, opto-electronics for space application, combustion gas sensor for microgravity environments and low-speed gas velocity sensors.

Workshops and Conferences

To kick off the Sensors Initiative at NASA Glenn Research Center, the IDEAS (Innovations, Demonstrations, Exhibits, Applications, and Spinoffs) conference focusing on microsystems was held in Cleveland in November 1999. This forum brought together experts from industry, government and academia to discuss industry requirements; the packaging and fabrication of sensors, motors/actuators and fluidics; and simulation and analysis. Showcased technologies included those dealing with health monitoring in harsh environments, including sensors, actuators, microelectronics, packaging and micromachining.

The Glennan Microsystems Initiative

NASA Glenn Research Center's Glennan Microsystem Initiative (GMI) is an endeavor involving Case Western Reserve University and Glenn to develop microsystem applications. The Battelle Memorial Institute, a non-profit organization that promotes new technology developments, manages the initiative. GMI recently received a $1.15 million Technology Action Fund Grant from the state of Ohio.

Microsystems are miniaturized electrical and mechanical devices as small as a human hair that will not only help ensure NASA's future missions are faster, better and cheaper, but also give Ohio's companies cutting-edge technology to compete in the international marketplace.

MEMS Revolution

Unique microsystems, or micro-electromechancial systems (MEMS), are designed to work in harsh environments. Microsystems are integrated, miniaturized, electrical and mechanical devices, such as sensors, motors, gears, valves and microprocessors, made from a silicon carbide-based material. Building on semiconductor manufacturing techniques, the devices can be made as small as the diameter of a human hair, combined with other devices in large numbers, and manufactured together on a single semiconductor chip. The results are devices that will operate in the harshest environments.

NASA's Goal

NASA hopes to create technology development partnerships through marketing our most promising sensor technologies to industry. These partnerships should leverage NASA and industry resources to yield win/win results. NASA hopes to then be recognized and valued as a "business partnering unit" for the agency's enterprises and programs. The ultimate goal is to establish high impact partnerships, benefiting both industry and the agency.

This issue of *Innovation* highlights NASA-sponsored sensors research that can play a role in everyday life.

The search for development partners within the sensors industry is just beginning.

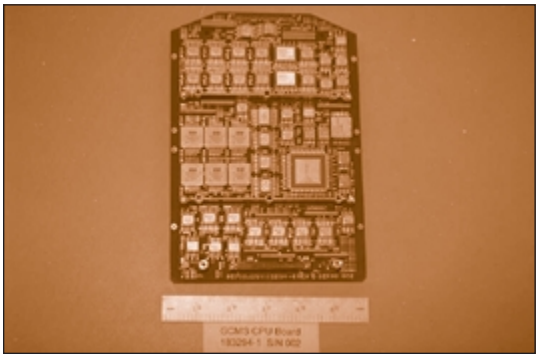
NASA Seeks Partnership with Sensors Industry

NASA IS SEARCHING FOR PARTNERS IN THE sensors industry to introduce promising new sensor technology to potential industry partners at an early stage in the development process. The agency is working to create high-impact partnerships that benefit NASA missions and sensors companies in the United States that are pursuing similar research goals.

The Sensors Initiative began in 1999, when the NASA Commercial Technology Program's Marketing Team developed and wrote the agency's marketing plan. One of the team's recommendations was the formation of a sensors industry-focused initiative, designed to increase NASA partnerships with companies in the sensors industry.

NASA's goal is to match its sensors technology needs for aerospace missions to those of sensors-sector companies, gauging where those needs overlap. These areas of overlap ultimately mean potential opportunities for companies to work with NASA to develop mutually beneficial, cutting-edge, profit-boosting technologies. With more than $1 billion spent each year on research and development, NASA has resources like no other company, laboratory or research facility.

NASA is seeking to develop commercial partnerships to develop sensors technologies. Below, a Gas Chromatograph Mass Spectrometer developed by NASA Goddard Space Flight Center to investigate the chemical composition, the origin and the evolution of the atmosphere of Titan, one of Saturn's moons. Photo provided by NASA Goddard Space Flight Center.



Overall trends in the sensors industry point to an expanding market and growing needs. A market assessment performed by NASA found that 75 percent of sensors are made in the U.S., while the U.S. employs 80,000 people in the industry. Growth in the instrumentation industry is reportedly 13.5 percent per year, with sales of approximately $49 billion in 2000. The sensors industry is a vital part of the nation's economy, and NASA wants to work with industry to increase its contribution.

The Sensors Initiative has already helped two organizations become more productive, a partnership with Resistance Temperature Detector Company, Inc. (RTD) and the Glennan Microsystems Initiative (GMI). NASA technology helped RTD produce thin film sensors to compile data without affecting the processes that are being monitored. Product improvement reduced production costs by 60 percent, and RTD expects to double its current annual sales of $2 million within two years.

GMI, at NASA Glenn Research Center, is an endeavor involving Case Western Reserve University and NASA Glenn Research Center to develop microsystem applications. The Battelle Memorial Institute, a non-profit organization that promotes new technology developments, manages the initiative for Glenn. Microsystems are miniaturized, electrical and mechanical devices as small as a human hair that will not only help ensure NASA's future missions are faster, better and cheaper, but also give Ohio's companies cutting-edge technology to compete in the international marketplace. "This is an extremely important collaboration," said NASA Administrator Daniel S. Goldin in praise of the effort. "Microsystems is an area of increasing international competition, and joint activities such as these are essential to ensure U.S. leadership. I believe this will greatly benefit NASA and Ohio industry."

GMI recently received a $1.15 million Technology Action Fund Grant from the state of Ohio for the development of three product platforms, including high-temperature pressure sensors, multi-species chemical sensors and in vivo catheter-based drug delivery systems. The work to be performed will also develop silicon carbide-based micro-electromechanical systems (MEMS) capability.

As a result of GMI, 13 companies have signed Joint Sponsored Research Agreements, three companies have agreed to do so and 14 companies are strong prospects to become joint sponsored research partners.

These successes are examples of the benefits that are available to other companies within the sensors industry. NASA is constantly searching for company partners to jointly develop or license some of the most cutting-edge sensors technologies ever developed—technologies that can help create new products or reduce costs to positively impact the bottom line.

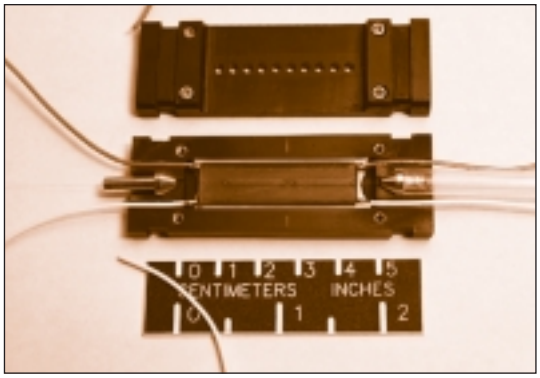
NASA scientists and engineers will provide a number of technical briefings and overview sessions on June 5-7 at the Sensors Expo in Chicago about the state of sensor research at the various NASA field centers.

- Dr. Walt Merrill, executive director of GMI, will discuss the status and future direction of GMI.

- Dr. Gary Hunter, senior research engineer at the Sensors and Electronics Technology Branch, will conduct a presentation about the activities of the Sensors and Electronics Technology Branch at NASA Glenn Research Center. This work includes the research, development and application of a wide range of microsystem sensor technology for harsh environments and safety applications.
- Bill Helms, chief of the Sensors and Instrumentation Branch at NASA Kennedy Space Center, will address technology development directions in sensors, data acquisition and hazardous gas detection.
- Dr. Sanghamitra B. Dutta, senior aerospace engineer in the detector systems branch, will discuss different ideas involving MEMS device development for instrumentation and spacecraft applications currently being pursued at NASA Goddard Space Flight Center.
- K. Elliot Cramer, senior scientist in the Nondestructive Evaluative Sciences Branch at NASA Langley Research Center will review research and technology development for advanced nondestructive evaluation and health monitoring of aerospace structures. The work includes a variety of optical and physical sensors integrated into intelligent systems to ensure structural integrity, configuration control, reliability and safety.
- Michael A. Marcolini, head of the Advanced Measurement and Diagnostics Branch at NASA Langley Research Center will discuss advances in aerospace technology, which increasingly require the use of global and/or non-intrusive quantitative measurement techniques. Quantitative flow measurements of interest include pressure, density, density changes, temperature and the velocity vector field. Surface measurements of interest include pressure, temperature, strains and shear stresses (skin friction), deformations, flow direction, transition detection, model attitude, and forces and moments on aircraft models. This talk will review recent research efforts to develop new sensing systems to provide such information, with emphasis on chemical and optical diagnostic micro-electromechanical systems (MEMS) and nano-device sensors and actuators, and related hardware and software.

In addition to the overviews, a number of NASA technologies will be discussed at Sensors Expo 2001. They include:

- UV/IR Hydrogen Flame Detector—this NASA Kennedy Space Center detector was specifically designed to detect hydrogen fires, while rejecting flare stack reflections resulting in false alarms;
- Compact Analytical Instruments for Planetary Surface Exploration—these technologies will include sub-optical imaging, chemical and elemental analysis and chemical sensing; and
- Rotary Sensor Technologies for Demanding Applications—these technologies include a 360-degree resolver signal-conditioner and an absolute rotary position sensor.



A fiber optics sensing system developed by NASA Langley Research Center.

Other topic areas include silicon carbide in high temperature applications, as well as other information on instrumentation and controls.

The keynote speaker for Sensors Expo 2001 is Dr. Harley Thronson, technology director for NASA's Space Science Enterprise. Thronson will speak about the latest Space Science Enterprise strategic plan, which is built around several goals that cannot be achieved without new generations of advanced sensors. Thronson will also discuss how sensor-systems technology will help NASA achieve its goals and how individual sensors-sector companies can partner with NASA to jointly develop these technologies.

NASA is searching for sensors industry partners to share the risks and rewards of new technology development efforts. Both parties will benefit from the partnerships—NASA from reduced mission costs and industry from reduced product development costs. The partnership approach will enable NASA to meet technology-driven program goals while providing industry with technologies for new products that will benefit the nation's economy.

For more information about the technical briefings and overview sessions, consult the Web site at *www.nasatechnology.com* or call NASA at 800/678-6882. For more information about the NASA Sensors Initiative, contact Bill Saettel at NASA Glenn Research Center, 216/433-2485, *William.J.Saettel@grc.nasa.gov* Please mention you read about it in *Innovation*.

NASA Satellite Technology to Monitor Vehicle Pollution

CITIES AND STATES MAY SOON HAVE A NEW high-tech tool in the battle against automotive air pollution, thanks to NASA satellite technology originally developed to track global greenhouse gases and Earth's protective ozone layer.

As envisioned, NASA's atmospheric remote-sensing technology will be adapted to an autonomous roadside system to monitor motor vehicle emissions. Cars and trucks will pass through a low-power light beam, without needing to stop or slow down. Space-age sensor technology will instantly analyze vehicle exhaust pollutants important to local and state governments working to meet federally mandated air quality standards.

"Taking an accurate reading of several exhaust products as a car passes by is a formidable challenge. We want to take a measurement of all the gases of interest every one-thousandth of a second over a period of a half-second. Fortunately, our newest remote-sensing technology has that capability," said Glen Sachse, senior research scientist at NASA Langley Research Center, Hampton, Virginia. Sachse is one of six team members who invented the highly sensitive electro-optical system at the core of the technology.

The patented NASA technology has been exclusively licensed to SPX Service Solutions of Warren, Michigan, for use in developing a new remote sensing device to monitor motor vehicle exhaust.

"Remote testing of vehicle exhaust will provide governments around the world with a fast, efficient and low-cost method to identify and reduce motor vehicle air pollution and greenhouse gases, which account for approximately one-half of all air pollution," said Craig Rendahl, remote-sensing business leader for SPX Service Solutions.

"With the number of vehicles on the road increasing every year, we believe there is a significant global market for technology of this nature," said Rendahl. "SPX will offer a basic unit which will be available in the fall of 2001. With the help of NASA, we expect to begin manufacturing a highly enhanced remote sensing device during the spring of 2002. This second-generation product will contain many other features, including the capability to test heavy-duty diesel vehicles."

"REMOTE TESTING OF VEHICLE EXHAUST WILL PROVIDE GOVERNMENTS AROUND THE WORLD WITH A FAST, EFFICIENT AND LOW-COST METHOD TO IDENTIFY AND REDUCE MOTOR VEHICLE AIR POLLUTION AND GREENHOUSE GASES."

The U.S. Clean Air Act mandates that a certain percentage of U.S. fleet vehicles be measured each year. The act allows for remote sensing as an option.

In a process called "clean screening," drivers who formerly took their vehicles to a service station for an annual emissions inspection would receive a notice in the mail certifying that their vehicle has passed twice in a 12-month period and that they do not have to submit to an emissions test—at least that's the expected outcome for most drivers. As individual roadside exhaust measurements are taken, the vehicle's license plate would be photographed and the data would be transmitted to a central collecting point.

Those drivers whose vehicles passed would save both time and money. Drivers whose vehicles failed or gave marginal readings would be identified for additional testing and possible emissions-related repairs.

In space, NASA uses remote-sensing devices mounted on satellites and backlighting from the sun to take global atmospheric measurements as part of its Earth Science Enterprise program. The program is aimed at expanding knowledge of Earth's environment in order to provide the scientific basis for sound policy decisions on environmental matters.

Service Solutions, a unit of SPX Corporation, provides special service tools, equipment program management, electronic diagnostics, emissions testing equipment and technical information services for the global motor vehicle industry.

For more information, contact Rosemary Baize at NASA Langley Research Center 757/864-7717, r.r.baize@larc.nasa.gov Please mention you read about it in *Innovation*.

Atmospheric Sensor Goes Industrial

SPECTRASENSORS, INC., A SPINOFF COMPANY of the Jet Propulsion Laboratory (JPL), Pasadena, California, has commercialized a gas sensor that was originally developed to measure the composition of the atmospheres of Earth and Mars.

SpectraSensors, Inc., located in Altadena, California, develops and manufactures tunable diode laser (TDL) gas sensor systems. The company's commercial TDL gas sensors have applications for oil and gas pipeline monitoring, industrial process control, smokestack monitoring, environmental monitoring, atmospheric science, aircraft safety and medicine. The technology is capable of detecting several gasses that are critical to industrial process control and environmental monitoring. Such detection includes water vapor, ammonia, acetylene, carbon dioxide, hydrogen fluoride and hydrogen chloride.

The heart of TDL systems is a small laser diode that produces a very narrow and specific wavelength of light tuned to a harmonic frequency of the target gas molecule in the near infrared band. The light causes the molecule to vibrate and, therefore, absorb energy. Once adjusted to the specific frequency of the molecule, the laser is minutely tuned to different wavelengths on either side of the target wavelength. The light energy being absorbed at the target gas frequency is compared to the light energy at the surrounding frequencies, resulting in an extremely precise measurement. New data are integrated every second, making the system quick to respond to variations in the target gas.

Natural gas distributors are currently using the company's extraction monitors to quantify levels of water vapor and carbon dioxide in their natural gas pipelines. The application calls for a rugged device that can withstand the harsh environments in these pipes, and measure moisture levels in methane pipes with low parts-per-million sensitivity. Today, most suppliers transport their product to customers through a shared pipeline infrastructure. Market rates for gas products are determined, in part, by the moisture level and purity of natural gas. Relative moisture levels indicate whether a gas is "wet" or "dry," while carbon dioxide levels tell the distributor whether the product is "clean" or "dirty." The requirement to measure humidity is also driven by the corrosive effect that water can have in combinations with other chemicals in the pipes. Corrosion can lead to leaks, which can create a potentially dangerous situation.

TDL gas-sensing technology is particularly good at detecting low levels of gases at the parts-per-million or even parts-per-billion level. With many industrial processes involving gas measurement of some kind, commercial applications for this technique are wide ranging. Possible applications include detecting moisture and carbon dioxide levels in natural gas pipelines and wafer fabrication process control for the semiconductor industry.

NASA and the Department of Defense's Ballistic Missile Defense Organization (BMDO) funded the development of the technology at JPL. The BMDO required the lasers for high-speed optical communications. NASA required the technology for atmospheric gas-sensing applications, using the TDL gas sensor on aircraft and balloons to study weather and climate, global warming and emissions from aircraft. In addition, six tunable diode laser systems were sent to Mars aboard the Mars Polar Lander to determine water vapor and carbon dioxide levels in the Martian atmosphere, and in gases evolved from heated soil samples.

For more information, contact Alice Wessen 818/354-4930 *alice.s.wessen@jpl.nasa.gov* Please mention you read about it in *Innovation*.

Wafer "Wiggle" Going Places

NASA'S PIEZOELECTRIC WAFER TECHNOLOGY has now been commercialized, sparking a broad range of potential applications in industry and scientific marketplaces. Application possibilities include the development of smaller heart pumps, more compact audio speakers, robotic "bugs" that walk, controls for airflow in automobile engines and quieter aircraft engines.

NASA Langley Research Center, Hampton, Virginia, invented and patented the Thin-Layer Composite-Unimorph Ferroelectric Driver and Sensor (originally called THUNDER®, a trademark later registered by Face International Corporation). This technology is also known as Prestressed Piezoelectric Composites (PPC).

Several years ago, NASA researchers were exploring the well-known phenomenon exhibited by piezo-

electric materials, which generate mechanical movement when subjected to a voltage. Such a property can be applied in electronics, optics, noise cancellation, pumps, valves, suppression of irregular motion and a variety of other fields. This technology can also be used as a sensor in such applications as microphones, non-destructive testing, and vibration testing.

A remarkable feature of these devices is their ability to provide inordinately large mechanical output displacements, as high as 30 times the thickness of the device itself. That "wiggle" is an order of magnitude greater than existing devices operating in the same frequency range. What's more, these composite piezoelectric structures are tougher than current commercially available piezoelectric materials. The revolutionary devices have greater mechanical load capacity than conventional piezoelectric disks and other piezoelectric wafers, and can easily be produced at a relatively low cost, lending themselves well to mass production. The fabrication process for these devices is readily controllable, resulting in highly uniform production.

NASA granted licenses to two Virginia-based companies: Face International Corporation of Norfolk, and Virginia Power and Electric Company of Richmond.

Face International has successfully commercialized its line of THUNDER® piezoelectric wafers. While offering piezoelectric actuators and sensors as standard products, Face International also sells "made-to-order" wafers, integrating customers' special configurations to fulfill the custom needs of clients.

Face International has exclusive license to develop actuator systems suitable for shaking concrete and processing other slurried materials. The company owns patents for using controlled acoustic energy (i.e., vibration or sound) to achieve the rapid setting of freshly poured concrete. The company also owns patents for THUNDER®-based pumps, switches and circuit breakers.

Face International is selling a variety of THUNDER® devices and is now capable of producing these and similar devices by the thousands on a monthly basis.

Development of Virginia Power's NASDRIV™ devices is currently underway. The company is authorized to sublicense in a wide range of applications, excluding concrete-related applications.

For more information, contact Al Lawver of Face International at 757/624-2121, *alawver@faceco.com* Please mention you read about it in *Innovation*.

"SMARTER" HIGHWAYS MEAN SAFER HIGHWAYS

Imaging Systems Technology, Inc. (IST), and its partner, GSYS Corporation, are working with NASA Glenn Research Center to design and market a "smart highway" collision avoidance system that can detect obstructions in a tractor-trailer's blind spots.

A system to detect objects in the blind spot of a tractor-trailer could save millions of lives on the nation's highways.

GSYS President Christopher Adams has invented and patented a collision avoidance system known as CoverHaul 18. The product utilizes the pre-existing trailer wiring as a means of powerline communication. This multiplexing technology allows for the exchange of power and data between tractor-trailers via the standard electrical connector. IST served as the specialist to design the sensors for the bumper systems.

"GSYS had the concept and the intellectual property, and we had the development capabilities," said Carol Wedding, IST president.

Used together, the technologies have the potential to save millions of lives on the nation's highways. Potential users of the Collision Avoidance System include the trucking industry, military vehicles and bus companies.

IST and GSYS are working with Glenn to develop a line of "Smart Highway Products" centered around collision avoidance. The companies teamed as one of the five winners of the first NASA Glenn Garrett Morgan Commercialization Initiative (GMCI) Commercialization Awards.

For more information, contact Gynelle Steele at NASA Glenn Research Center *gynelle.steele@grc.nasa.gov* Please mention you read about it in *Innovation*.

Sensor Webs Are Virtual Explorers

WIRELESS WEBS OF TINY SENSOR PODS created to aid in monitoring biological activity on Earth may eventually be used to help explore other planets.

Scientists at NASA's Jet Propulsion Laboratory (JPL) have created the webs, which will be first used to provide additional information on Earth-based issues like the carbon cycle. Later, the webs could be used to search for evidence of life on Mars or explore the moons of Jupiter.

A sensor web is a system of wireless, intracommunicating, spatially distributed sensor pods that can be deployed to monitor and explore new environments. According to Kevin Delin, one of the scientists who developed the sensor web concept, each pod collects local information through its sensors and communicates that information wirelessly to neighboring pods. In this way, the information is distributed throughout the entire web. The information is then transmitted to a remote source, such as a computer or mobile phone. Eventually, if the web were used in space exploration, it would transmit the information to a satellite or space probe.

"A sensor web is capable of automated reasoning," Delin said, "because it can perform autonomous operations in uncertain environments, respond to changing environmental conditions and carry out automated diagnosis and recovery. Sensor webs could have as much an impact on the use of sensors as the Internet did on the use of computers.

"Each little pod is like a cell of your body," Delin said. "The sensor webs are different from distributed sensors in that distributed sensor networks gather data and communicate it to a central point. The sensor web pods gather and, more importantly, share information with other pods. The sensor webs modify their behavior on the basis of the collected data."

"A SENSOR WEB IS CAPABLE OF AUTOMATED REASONING. SENSOR WEBS COULD HAVE AS MUCH AN IMPACT ON THE USE OF SENSORS AS THE INTERNET DID ON THE USE OF COMPUTERS."

Sensor Web 3 is currently being developed for the Huntington Botanical Gardens in San Marino, California, also the test site for Sensor Web 2. A botanical greenhouse was chosen for the deployment site of the web for several reasons, according to Delin. "Many basic applications, particularly those in astrobiology and Earth science, would require a suite of sensors similar to those needed in this environment," he said. "Second, a greenhouse would provide somewhat harsh conditions, such as high temperatures, high humidity and dirt, that would make a field test meaningful."

The information collected by Sensor Web 3 includes measurements of air temperature, soil temperature, relative humidity, soil moisture and the light level. "Sensor webs offer us the means to make sensitive measurements over large areas," Delin added. "A major thrust of our current effort is to develop a sensor web that can detect, identify and monitor biological activity. For example, trace biosignature gases are very important if you are a biogeochemist trying to understand the carbon cycle on Earth or searching for microorganisms living beneath the surface of a planet."

The sensors themselves can determine the cost of deploying a sensor web, since the sensors and hardware being used in the sensor pods are commercially available, off-the-shelf products that have been developed for computers and mobile telephones.

The JPL Sensor Webs Project is also beginning to develop a partnership with NASA Kennedy Space Center to look at marine biology in the area.

According to Delin, the sensor web also has applications for saving human life in space and on Earth. The sensor web can show the direction of gas flow and available exit routes by providing vectored direction in both time and space. "The webs can be used in space to not only detect a loss of pressure in a spacecraft, but to pinpoint the leak so the correct section of the craft can be closed off.

"And imagine if you had sensor webs in your house," Delin said, "so that instead of just having a smoke alarm go off, you actually had an idea which direction the fire is coming from so you knew how to escape it."

For more information, visit *http://sensorwebs.jpl.nasa.gov*, or contact Kevin Delin at Jet Propulsion Laboratory, 818/354-9647, *kevin.delin@jpl.nasa.gov* Please mention you read about it in *Innovation*.

Satellite Sensors Find Fish and Food

SCIENTISTS USING SATELLITE DATA DISCOVered an unusual, long-lasting, whirlpool-like ocean eddy that generated a dramatic increase in the marine food supply off the Hawaiian coast in 1999.

The eddy, named Loretta, began spinning up in the Alenuihaha Channel between the islands of Hawaii and Maui during mid-May 1999 and maintained a presence in the lee of the Hawaiian Islands until January 2000. Over the eight-month period, the eddy's churning motion brought up a great amount of nutrients from the ocean depths, enhancing the plankton population on the ocean's surface, and providing a banquet for marine life.

Several organizations collaborated to track Loretta and other Hawaiian eddies and their ecological benefits. The University of Hawaii, NASA and the National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Service (NMFS) integrated information from two independent satellite sensors that measure sea surface temperature (SST) and ocean color. The Sea-viewing Wide Field-of-View Sensor (SeaWiFS) satellite tracked ocean chlorophyll, and NOAA's Geostationary Operational Environmental Satellite-10 (GOES) satellite tracked sea surface temperatures. Data from shipboard measurements taken aboard the NOAA ship Townsend Cromwell were also used to see the efforts of Loretta in subsurface waters, since satellite observations are restricted to the ocean surface.

"Eddies naturally occur in this locale for periods of several weeks to a few months, but Loretta

SENSOR TECHNOLOGY INDUCTED INTO HALL OF FAME

An advanced sensor developed at NASA's Jet Propulsion Laboratory (JPL) in Pasadena, California, was inducted into the U.S. Space Foundation Hall of Fame on April 12, 2001, in recognition of its potential uses in medicine, firefighting and industry, as well as astronomy.

The Quantum Well Infrared Photodetector (QWIP) technology has been licensed for various commercial applications, including non-invasive detection of breast and skin cancers.

Physicians use it during brain surgery to visualize a tumor's perimeter. The QWIP camera's ability to see through dust and smoke has proven useful to firefighters and helicopter camera crews by allowing them to see forest fire hot spots from the air through heavy smoke. The technology also has many other potential uses from search and rescue, to spotting faulty welds and blockages, to volcano observation.

"It is a great pleasure to see something we developed being used for public benefit," said Sarath Gunapala, co-inventor and principal engineer of the sensor developed at JPL, "especially in medical applications, such as the early detection of cancer."

The ability of the camera to see in the infrared has been useful for NASA. Astronomers at Palomar Observatory have also taken advantage of the ability to see in the infrared through dust clouds and image deep into dusty star-forming regions where visible sensors cannot penetrate.

The U.S. Space Foundation's Space Technology Hall of Fame honors individuals, organizations and companies who have taken technologies originally designed for the space program and later adapted them for commercial application on Earth. The QWIP technology was inducted during the Foundation's National Space Symposium, April 9–12, 2001, in Colorado Springs, Colorado. Three other JPL technologies have made the Hall of Fame: the Active Pixel Sensor in 1999 and, in 1994, Digital Image Processing and an Excimer Laser Angioplasty System.

For more information, contact Surath Gunapala of Jet Propulsion Laboratory, 818/354-1880, *sarath.d.gunapala@jpl.nasa.gov* Please mention you read about it in *Innovation*.

persisted for eight months according to satellite data," said Robert Bidigare of the University of Hawaii. After January 2000, Loretta started to move slowly westward, and eventually weakened beyond detection, but not before bringing a tremendous amount of deep-sea nutrients to the surface of the ocean.

Eddies are usually 30-125 miles (50-200 km) in diameter, and resemble hurricanes in the water. Like hurricanes, each eddy is given a name to keep better track of it. In 1999, researchers named the eddy "Loretta." Around the Hawaiian Islands, eddies are caused when northeasterly trade winds interact with the topography of the islands. Eddies occur most frequently in the Alenuihaha Channel off the Kona coast of the Big Island of Hawaii, where they can be observed throughout the year.

SeaWiFS generated eight-day composite pictures of the ocean color that showed scientists where the nutrients and the eddy were located.

Eddies bring an increase in organisms that comprise the marine food web, attracting fish and fishers. The swirling motion of eddies cause nutrients that are normally found in colder, deeper waters to come to the surface. Normally surface waters are nutrient-limited, and when an eddy occurs, the cold water upwelling substantially increases chlorophyll and plankton production, as it did with Loretta.

The SeaWiFS satellite tracked Loretta's movement by monitoring chlorophyll. The chlorophyll are contained in single-celled ocean plants, smaller than the size of a pinhead, called phytoplankton. Increases in phytoplankton cause higher levels of the green chlorophyll pigment, which in turn change the color of the ocean surface. Although microscopic, phytoplankton can bloom in such large numbers that they can change the color of the ocean so much that they can be measured from satellites.

By looking at the color of an area of the ocean, the concentration of phytoplankton can be estimated. Because phytoplankton changes an ocean's color, they are ideal candidates for tracking eddies and currents, detecting pollution and observing meteorological events. SeaWiFS generated eight-day composite pictures of the ocean color that showed scientists where the nutrients and the eddy were located.

NOAA's Coast Watch program also monitored Loretta using imagery from the GOES-10 satellite to generate three-day composites of sea surface temperatures. By watching where the colder water moved, they were able to track Loretta's movements. According to Michael Seki of the NMFS, "Some of the strongest temperature gradients associated with Loretta occurred during late August-early September 1999. The sea surface temperature in the center of Loretta was 23.5 degrees Celsius (74.3 degrees Fahrenheit), a lot cooler than the waters outside of the eddy."

Fishers constantly monitor eddies using satellite data because they are such large circulation features that they are difficult to see with the naked eye. When an eddy is spotted, fishers set their hooks and lines around and through these features. Because of the increase in food, eddies are known to increase the concentration of fish and thus, fishers harvest greater catches.

A paper authored by Michael Seki of the U.S. NMFS appears in the April 15, 2001 issue of *Geophysical Research Letters*, and details the increased plankton observed in response to eddies in the open ocean near Hawaii. The article focuses on the increased ability to measure sea surface temperature in real-time by using the GOES satellite. Co-authors of the paper include Jeffrey Polovina and Russell Brainard of NMFS, Honolulu Laboratory; Robert Bidigare and Carrie Leonard of the University of Hawaii, Department of Oceanography; and David Foley of the Joint Institute of Marine and Atmospheric Research, University of Hawaii and NOAA.

This project is collaborative research effort between the NMFS and NASA-funded projects. The study was also partially supported by the Pelagic Fisheries Research Program administered through the University of Hawaii, School of Ocean and Earth Science and Technology.

Additional information is available on the Internet at: *http://www.gsfc.nasa.gov/gsfc/earth/eddy/eddy.htm* For more information, contact Michael Seki, National Marine Fisheries Service, NOAA Honolulu Laboratory, ✉ *mseki@honlab.nmfs.hawaii.edu*, 808/983-5393, 808/983-2902. Please mention you read about it in *Innovation*.

Smart Structures Monitor Spacecraft Health

MATERIAL DEGRADATION AND CONTAMINATION due to long-term exposure to the space environment is a serious hazard for space structures. These materials have many damage-detection mechanisms and failure prediction methodologies yet to mature. In addition, once placed in orbit, the structures are difficult to inspect.

Environmental factors degrade materials and structures through surface erosion, impacts due to micrometeorites, outgassing, launch, deployment and operational loads, vibration, and thermal cycling. These effects can severely reduce both the strength and stiffness of a composite material. In order to successfully use composite vehicles and platforms in space, provisions for monitoring structural degradation must be incorporated into the design of the structure—"smart" aerospace structures. The data obtained from this monitoring can be used to automatically modify the control algorithms of the structures in real-time.

Innovative Dynamics, Inc., (IDI) of Ithaca, New York, developed a technology for monitoring the structural health of spacecraft applications. The system, designed specifically for composite structures, uses an array of embedded piezoelectric elements and a broadband excitation source to excite modal structural frequencies. Specific flaws can be detected using pattern recognition techniques.

A smart structure is a structure instrumented with arrays of sensors, computers and actuators that monitor its load environment and structural integrity throughout its life and take corrective action when required.

According to Gail Hickman, vice president of research and development for Innovative Dynamics, "This technology would significantly boost the reliability, maintainability and performance of future aerospace structures. The sensor arrays will play the role of the nervous system, a computer architecture will play the role of the brain and actuators will play the role of muscles."

This work was funded under an SBIR program sponsored by NASA's Jet Propulsion Laboratory. The system consists of piezoelectric sensors integrated throughout the structure and a hierarchical computing architecture to process the sensor information and respond as damage is detected. The system works by mechanically exciting the structure with broadband energy and monitoring changes in the structural vibration response. Shape, amplitude and distortion of the vibration signals provide useful information concerning the location and severity of the damage. Pattern recognition techniques are used to analyze the vibration signature and assess the damage. The use of multiple sensors provides a means of locating the damage as well.

A structural integrity monitoring system developed by Innovative Dynamics, Inc., will make it easier to inspect composite structures deployed in space. Photo provided by Innovative Dynamics, Inc.

For more information, contact Gail Hickman of Innovative Dynamics, 607/257-0533, *info@idiny.com* You can also visit IDI's Web site at *http://www.idiny.com* Please mention you read about it in *Innovation*.

First Scramjet-Powered Hypersonic Flight

IMAGINE A NEW BREED OF SPACE transportation vehicle, able to fly at seven times the speed of sound, using a next-generation air-breathing jet engine. NASA takes a hypersonic leap into the future of aerospace technology with the flight of the scramjet-powered X-43A.

It will be the first time a non-rocket propelled, air-breathing engine has powered a vehicle in flight at hypersonic speeds, or five times the speed of sound. An aircraft moving at Mach 5 would travel about one mile per second, or about 3,600 mph at sea level, far faster than any air-breathing aircraft has ever flown.

Unlike a rocket that carries its own oxygen for combustion, the X-43A's scramjet scoops air from the atmosphere, making the aircraft lighter, which enables it to carry heavier payloads. The hydrogen-fueled aircraft has a wingspan of approximately 5 feet, measures 12 feet long and weighs about 3,000 pounds.

The first unpiloted X-43A and its Pegasus booster rocket will be air-launched from a B-52 from NASA

Dryden Flight Research Center, Edwards, California. The booster will accelerate the X-43A to Mach 7 at approximately 95,000 feet. At booster burnout, the X-43A will separate and fly under its own power on a preprogrammed flight path.

The NASA Hyper-X Program's development and flight testing of the X-43A vehicle is conducted jointly by Dryden and NASA Langley Research Center, Hampton, Virginia. "The Hyper-X Program and the X-43A Flight Project have forged a very fruitful partnership and national asset," said Joel Sitz, Dryden's X-43A project manager. "What the country is witnessing is the rebirth of hypersonics."

Sitz added, "After a successful X-43A mission, the 'brain trust' will exist to move forward with future propulsion-research vehicles that will ultimately result in more efficient space access vehicles."

"The Hyper-X program takes what we've been doing for the last 40 years in wind tunnel research to flight. Flight is reality," said Vince Rausch, Hyper-X program manager at Langley. "The program is structured around the scramjet engine and should be a major leap forward in the national capability for access to space. The country is looking for safer, more flexible, less expensive ways to get to space, and that's what the scramjet engine would bring us."

Scramjet technology could also allow more traditional aircraft-like operations of launch vehicles, with horizontal take-off, landing and servicing, which could greatly reduce operational cost and time between flights.

Three X-43A flights are planned; the first two will fly at Mach 7 and the third at Mach 10. Valuable performance data will be relayed electronically to Dryden and Langley. Each experimental aircraft will fly once in the Naval Air Warfare Center Weapons Division Sea Range off the southern coast of California and impact into the Pacific Ocean.

Like the comparatively slower ramjet counterpart, the scramjet has a simple mechanical design with no moving parts. However, scramjet combustion occurs at supersonic air speeds in the engine. Rather than using a rotating compressor like a turbojet engine, the forward velocity and vehicle aerodynamic design compress air into the engine. There, fuel, usually hydrogen, is injected and the expanding hot gases from combustion accelerate the exhaust air and create thrust. In the case of X-43A, the thrust will propel the vehicle at hypersonic speeds up to Mach 10.

The first free-flight test will be approximately three weeks after an upcoming captive-carry flight, where the B-52 flies with the X-43A "stack" to the test range for a series of flight systems tests.

Following the first series of X-43A hypersonic flights, the next step is an expanded hypersonics research ground and flight program currently in place as part of the Advanced Space Transportation Program, which is led by NASA Marshall Space Flight Center, Huntsville, Alabama.

The vehicle contractor team, led by MicroCraft in Tullahoma, Tennessee, includes The Boeing Company, Seal Beach, California, and GASL, Inc., Ronkonkoma, New York. The booster is a modified Pegasus rocket from Orbital Sciences Corporation, Chandler, Arizona.

For more information, visit *http://www.dfrc.nasa.gov/Projects/hyperx/x43.html* or *http://www.dfrc.nasa.gov/Projects/HyperX/index.html* or contact Joel Sitz at NASA Dryden Flight Research Center 661/276-3666, *joel.sitz@dfrc.nasa.gov* Please mention you read about it in *Innovation*.

X-37 Program Gets Boost

IN THE EARLY MORNING OF MARCH 14, 2001, THE X-40A glided to the runway at Edwards Air Force Base in California, its nose wheel set down smoothly and the test vehicle rolled to a gentle stop. However, no pilot exited the craft, for there was no pilot. The X-40A flew itself, guided by its onboard systems.

"It was truly a beautiful sight, and cause for celebration," said Susan Turner, NASA's X-37 program manager at NASA Marshall Space Flight Center in Huntsville, Alabama.

The X-40A's free flight and landing were conducted as part of the X-37 program, intended to reduce the risk of flight testing the X-37, not from 15,000 feet like the X-40A, but from low-Earth orbit. The X-37 is an experimental re-entry vehicle that will enable NASA to test advanced technologies in the harsh environment of space and in returning through Earth's atmosphere.

This first successful test of the X-40A by NASA was a big step forward for the X-37 program. Its primary objective was to validate the vehicle's Computed Air Data Systems (CADS), which also will be used in the flight control system of the X-37.

"Our initial review of the test shows the vehicle's performance matched our predictions nearly perfectly," said Turner.

This flight also demonstrated the kind of teamwork that will be needed for NASA to develop a second-generation reusable launch vehicle capable of replacing today's Space Shuttle. The Boeing Company, NASA's partner in X-37, made major modifications to the X-40A, on loan from the U.S. Air Force, which also participates in the X-37 program. NASA Dryden Flight Research Center, with the cooperation of Edwards Air Force Base, conducted the test. The X-40A was lifted into the sky and released by a U.S. Army Chinook helicopter provided by Fort Rucker, Alabama.

The X-37 program consists of three phases of flight testing: the X-40A free flight series is phase one; phase two will be atmospheric testing, with the X-37 being dropped from a B-52; phase three will be the orbital test flights.

"Incremental testing is a cost-effective approach to designing an experimental spacecraft," said Turner. "By leveraging an existing asset—the X-40A—we obtain valuable information which enhances the likelihood of mission success for the X-37.

"Upcoming free flights will push the envelope further. Each time, we'll change some of the test variables of the X-40A to check the vehicle's controllability and maneuverability in a different flight situation. The results will help us determine our safety parameters when we fly the X-37," said Turner.

A second free flight test of the X-40A took place in early April. The objectives were the same as the first flight; however, engineers modified control variables to see the vehicle's response.

The X-40A test vehicle was built in 1998 for the Air Force by The Boeing Company at its Seal Beach, California, facility. It has a fuselage length of 22 feet, a wingspan of 12 feet and weighs about 2,600 pounds. It is an 85 percent scale version of the X-37.

The X-37 government team, led by the Marshall Center, includes NASA Ames Research Center, Moffett Field, California; Johnson Space Flight Center, Houston, Texas; Kennedy Space Center, Cape Canaveral, Florida; Goddard Space Flight Center, Greenbelt, Maryland; Langley Research Center, Hampton, Virginia; Dryden Flight Research Center and the Air Force Flight Test Center, both at Edwards Air Force Base in Edwards, California; and the Space and Missile Systems Center and the Air Force Research Laboratory in Albuquerque, New Mexico. Boeing's facility at Seal Beach, California, leads the X-37 industry team.

For more information about the X-37 or the X-40A, contact Mark Skoog at NASA Dryden Flight Research Center, 661/276-5774, *mark.skoog@dfrc.nasa.gov* Please mention you read about it in *Innovation*.

OXYGEN SENSORS QUALIFIED FOR FLIGHT

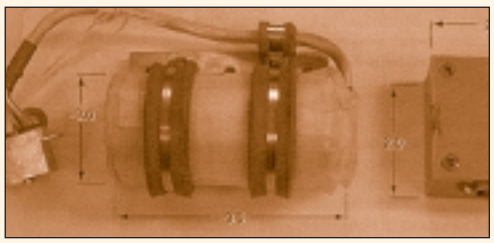
NASA Dryden Flight Research Center has conducted rigorous testing and qualified an inexpensive commercial off-the-shelf (COTS) oxygen sensor that, during flight tests, accurately and reliably aids assessment of the hazards associated with propulsion systems supplemented by oxidizers. Future flight test vehicles continue to rely on such energetic propellants as liquid and/or gaseous oxygen and hydrogen for purposes of demonstration because these propellants deliver high, specific impulses.

In preparation for flight testing in the Linear Aerospike SR-71 Experiment (LASRE) program, commercial sensors intended originally for medical and automotive application were qualified for flight. After a rigorous process of qualification and calibration, the sensors have now been added to the Hyper-X program, a proposed experimental hydrogen-fueled hypersonic aircraft, and are scheduled for use in future flight test projects.

The sensor in question is a commercial-grade miniature fuel cell, a small transducer that converts chemical energy into electrical energy. The vendor has estimated the sensor life expectancy to be approximately 2.4 years. However, because of the criticality of these sensors, it was decided that in the LASRE project, each such sensor would be replaced when its response deteriorates or it reaches a calendar life of 1.5 years.

Twelve of the sensors and their respective thermal controllers were integrated into the LASRE flight test fixture and were flight tested to a speed of Mach 1.6 and an altitude of 52,000 feet. Eight of the original twelve sensors remained onboard after removal of the LASRE for some follow-on flight tests at speeds up to Mach 3.03, altitudes to 73,000 feet and exposure to internal temperatures greater than 130 degrees Fahrenheit. Even though the temperatures rose above the temperature-controller limits and the manufacturer's specifications for operation, the oxygen sensors exhibited no significant drift.

Four sensor suites are to be incorporated into the Hyper-X airplane for safety during the flight test in which the Hyper-X will be carried by a B-52 airplane. These sensors will be used to verify the desired and expected chemical inertness—specifically, the lack of oxidizing gas—in the interior of the vehicle. They are being calibrated in much the same manner as in the LASRE program, but dynamic-response and sensor-recovery tests will be performed in addition, for comparison with results of tests in the boost and free phases of the flight of the Hyper-X.



A commercially available oxygen sensor and its temperature controller have been qualified for flight and will be used aboard the Hyper-X airplane. Photo provided by NASA Dryden Flight Research Center.

For more information, please contact Neal Hass at NASA Dryden Flight Research Center 661/276-2641 *neal.hass@mail.dfrc.nasa.gov* Please mention you read about it in Innovation.

SBIR Leads to Plant Fluorescence Sensor

GROWERS AND FORESTERS ALIKE HAVE YET another source for improving the health of their crops due to the work of a Billerica, Massachusetts, company funded through the Small Business Innovation Research (SBIR) Program at NASA Stennis Space Center. Aerodyne Research, Inc. has successfully developed the Plant Fluorescence Sensor (PFS), a real-time sensor that passively monitors plant health by remotely sensing plant responses related to the fundamental process of photosynthesis.

As NASA's lead center for the commercialization of remote sensing technologies, the NASA Earth System Science Office (ESSO) at Stennis incorporates the technology of remote sensing into its efforts. One focal area of research is the pre-visual sensing of unhealthy, or stressed, plants. Aerodyne's development of the PFS through the SBIR Program is in response to one of the ESSO's challenges.

Aerodyne designed and built the PFS as a robust sensor of sunlight-excited chlorophyll fluorescence. It provides for the real-time, in situ remote sensing of photosynthetic activity in plants. This sensor, which operates as a Fraunhofer line discriminator, detects light at the cores of the lines comprising the atmospheric oxygen A-band and B-band, centered at 760 nanometers (nm) and 688 nm respectively. Fraunhofer lines identify the spectral regions where little or no solar radiation reaches the surface of Earth, providing an area free of solar background interference. These bands also correspond to wavelengths in the red and far-red chlorophyll fluorescence bands. The intensity and spectral band shape of chlorophyll fluorescence in green plants has been linked to the physiological status of plants, thus providing a good indicator of general plant health.

The measurement of chlorophyll fluorescence emission has generally been performed with active stimulation in laboratory settings. However, the passive measurement of in situ solar-stimulated plant fluorescence has proven to be a more difficult task because the intensity of plant fluorescence, under the best of circumstances, is several hundred times less than that of sunlight.

The PFS does not use an interferometer or spectrometer. Rather, it is designed to pass the light collected from the fluorescing plants through a cell containing oxygen at low pressure. The oxygen absorbs the energy and subsequently re-emits photons that are detected by a photomultiplier tube. Since the oxygen in the cell absorbs light at exactly the wavelengths that are absorbed by the oxygen in the atmosphere, the residual response to sunlight is minimal. The induced fluorescence signal provides an immediate, absolute measurement of plant fluorescence intensity in the narrow bands in which the sensor responds.

Aerodyne has built and tested three experimental prototypes using off-the-shelf components. The PFS's core components are relatively inexpensive, have few moving parts and are based on established technologies, thus increasing their reliability. The company has successfully conducted numerous field tests using the patented PFS on a variety of crops, including hydroponic bean gardens, sorghum plots, cotton plots and greenhouse-grown Laurel oak seedlings. These tests indicated that the PFS is capable of pre-visual detection of plant stress resulting from water and nitrogen deficiencies as well as other applied stresses.

Aerodyne Research sees a market for the Plant Fluorescence Sensor as a passive remote monitor of plant health. Applications include site-specific agriculture, hydroponic growing environments, crop condition assessment, damage assessments due to a variety of stressors, forestry and ecological monitoring—including carbot sequestration and soil remediation. Expectations are that passive remote sensing of plant fluorescence will be proven as a reliable and readily available tool for the early detection of plant stress, thereby allowing for corrective measures and the realization of substantial improvement in yield.

This unique remote sensing product falls at the very center of the NASA Earth Sciences Enterprise (ESE) and

A real-time sensor that passively monitors plant health can improve the health of plants by monitoring their photosynthetic activity. Photo provided by NASA Stennis Space Center.

is directly representative of the Memorandum of Understanding between NASA and the U.S. Department of Agriculture for joint applications research and technology in agriculture, forestry and other natural resources management. This technology also supports the ESE commitment to the U.S. Global Change Research Program.

Aerodyne Research has provided research and development (R&D) services since 1970 to commercial and government clients working to solve national and international problems. The R&D staff is organized into six technology centers that address a wide range of topics requiring expertise in the physical and engineering sciences.

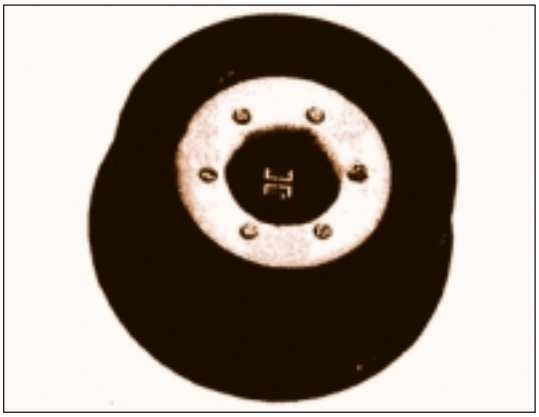
Aerodyne has elected to retain title to this invention, which has been credited to Dr. Paul Kebabian.

For more information about the Plant Fluorescence Sensor, contact Dr. Herman Scott at Aerodyne Research 978/663-9500, ext. 267, or log on to Aerodyne's Web site at *http://www.aerodyne.com*

Pressure Sensors Developed for High Temperatures

A HIGH-TEMPERATURE PRESSURE SENSOR for aircraft engine testing has been developed through a Small Business Innovation Research (SBIR) contract between NASA Glenn Research Center (GRC) and Kulite Semiconductor Products, Inc.

The silicon carbide (SiC) pressure sensor is designed for use at temperatures as high as 500 degrees Celsius, which is approximately 50 degrees higher than temperatures that can be withstood by currently available silicon pressure sensors. The sensor is capable of operating at 500 degrees Celsius for several hours. Silicon carbide exhibits excellent thermal and mechanical properties at high temperatures; further, it has large coefficients of piezoresistance. This combination of properties makes the material well suited for high-temperature electromechanical sensors.



A high-temperature pressure sensor developed through an SBIR contract between NASA Glenn Research Center and Kulite Semiconductor Products, Inc., is usable at temperatures up to 500 degrees Celsius. Photo provided by NASA Glenn Research Center.

"Engine companies have always been looking for pressure sensors capable of operating at higher temperatures," said Dr. Glenn Beheim, instrumentation research engineer at GRC. "Kulite and other sensor manufacturers have been increasing the operating temperatures of silicon pressure sensors for some time, but they have pretty much reached the maximum temperature at which silicon can operate. For temperatures of 500 degrees Celsius and higher, silicon deforms plastically. Silicon carbide works quite well at 500 degrees Celsius and eventually will allow us to go to even higher temperatures."

Silicon carbide microfabrication and high-temperature packaging technologies were developed under Phase II of the SBIR contract with Kulite. Under Phase III of the contract, Kulite will provide NASA Glenn with twelve prototype sensors. One of these prototypes was successfully tested in the compressor of a gas turbine engine in early fall of 2000 at Honeywell in Phoenix, Arizona.

In addition to use in aircraft engine development and testing, the sensors can also be used for fast response pressure measurements in the compressor hot section for aircraft stall detection and control. There is also potential for other high-temperature pressure measurement applications, including tank and ship engines, power plants and material-processing systems.

According to Beheim, eventual goals of the project are to produce pressure sensors with in-package temperature compensation and to increase the maximum operating temperature. In addition, tests with Pratt & Whitney, a unit of United Technologies Corporation of Hartford, Connecticut, are being discussed. Work on the sensors is being conducted with engine manufacturers through the Propulsion Instrumentation Working Group (PIWG), a consortium of engine companies and government agencies. PIWG has guided the design of the sensor to ensure that it meets the requirements of the engine manufacturers. PIWG is also coordinating the on-engine testing of the sensor.

Kulite designs, develops and manufactures solid-state semiconductor pressure sensors using piezoresistive technology.

The Advanced High Temperature Engine Material Technology Program (HITEMP) and Higher Operating Temperature Propulsion Components (HOTPC) Program provided funding for the project.

For more information, contact Glenn Beheim at NASA Glenn Research Center, 216/433-3847, *beheim@grc.nasa.gov* Please mention you read about it in *Innovation*.

Imaging Revolution Underway

AN IMAGING REVOLUTION IS CURRENTLY underway that is changing the way camera chips are fabricated and operated. Existing imaging devices used for video cameras and digital still cameras largely incorporate charge coupled device (CCD) and complementary metal-oxide-semiconductor (CMOS) image sensors. Although these devices have made strides in recent years with important gains in the consumer electronics markets, the complex nature and low device yield of CCDs remain problematic. Enter active pixel sensors (APSs).

Sensors Unlimited, Inc., under a NASA Small Business Innovation Research (SBIR) contract at Goddard Space Flight Center, has developed an APS using photodiodes and Junction Field Effect Transistors (JFETs). APSs increase the digital possibilities of infrared cameras. They detect light using an integrated amplifier in each pixel. Monolithic circuit functionality is integrated at every pixel.

APSs are usually fabricated using the CMOS process. This is the same process used to create most integrated circuits, including high performance microprocessors. The advantage of such devices include: low power dissipation, enhanced pixel circuitry and higher device yield than their CCD counterparts.

However, when active pixel sensors are fabricated using silicon circuitry, they do not respond to light beyond the 1.1 mm cutoff wavelength of silicon. In the near infrared, the preferred imaging material is indium fallium arsenide (InGaAs). This detector material has a uniformly high quantum efficiency of more than 80 percent at wavelengths from 0.9 to 1.7 microns. It was developed to be a detector for fiber-optic communications. In addition, high performance electronics may also be fabricated on the same chip as the photodiodes.

One of the challenges of the development was the ability to fabricate large-scale circuits with good performance characteristics in the indium phosphide (InP) materials system. The ability to fabricate such a device using InP-based materials is due directly to a patented "P-encapsulated" junction field effect transistor technology. This technology results in low-leakage transistors, less than 10 picoamps at pinch-off. The conductive InP channel is pinched off on all sides of the transistor, including the bottom.

The final sensor chip consists of an 8x8 array of InGaAs photodiodes, with a source follower circuit in each unit cell. An individual pixel is accessed by "turning on" its X and Y select transistors and reading the voltage at the output transistor. The device incorporates a total of 64 photodiodes and 212 transistors.

In addition to applications as an imaging device, the circuit may be operated as a two-dimensional fiber optic receiver for cross-connect applications. In this mode, the reset transistor functions as a load resistor for the photodiode. This mode is similar to that of a high-impedance, fiber optic receiver. As current flows through the photodiode, the voltage drop that appears at the gate of the input transistor is modulated and amplified at the output.

This technology will enable 10 gigabit (one gigabit equals 1,000,000,000 bits) per second receiver circuits needed for rapid internet growth, to be made in an array fashion, allowing network operation up to one terabit per second (one terabit equals 1000 gigabits). Other commercial applications of this innovation include inspection of fiber optics, eye-safe covert surveillance, spectroscopy, laser beam profiling, laser and light detection and ranging (Ladar and Lidar), machine vision, telecommunications and other applications where near-infrared detection is required.

NASA is using this technology in the Atmospheric Corrector (AC) instrument that was flown on the Earth Observing-1 (EO-1) mission launched in November 2000. The AC was tested for its ability to increase the accuracy of surface reflectance estimates.

For more information, contact Dr. Christopher Dries at Sensors, Inc. 609/520-0610 *jcdries@sensorsinc.com* Please mention you read about it in *Innovation*.

SMALL BUSINESS PROJECTS SELECTED

NASA has selected 27 research proposals for negotiation of Phase II contract awards for the Small Business Innovation Research (SBIR) Program. The selected projects, which have a total value of approximately $16 million, will be conducted by 25 small, high-technology firms located in 13 states.

A total of 267 proposals were submitted by SBIR contractors completing Phase I projects. These proposals were evaluated to determine that they met SBIR Phase I objectives and are feasible research innovation for meeting agency needs. The new selections are in addition to 110 proposals selected last year.

Phase II continues development of the most promising Phase I projects. Selection criteria include technical merit and innovation, Phase I results, value to NASA, commercial potential and company capabilities. Funding for Phase II contracts could be up to $600,000 for a two-year performance period.

For more information, contact Michael Braukus 202/358-1979 *mbraukus@hq.nasa.gov* or visit *http://sbir.nasa.gov* Please mention you read about it in *Innovation*. The NASA SBIR Program Management Office is located at NASA Goddard Space Flight Center, Greenbelt, Maryland, with executive oversight by NASA's Office of Aerospace Technology, NASA Headquarters, Washington, DC. Individual SBIR projects are managed by NASA's ten field centers.

Technology Opportunity Showcase *highlights some unique technologies that NASA has developed and that we believe have strong potential for commercial application. While the descriptions provided here are brief, they should provide enough information to communicate the potential applications of the technology. For more detailed information, contact the person listed. Please mention that you read about it in* Innovation.

Packaging Technology Operable to 500 Degrees Celsius for High-Temperature Microsystems

Researchers in the Instrumentation and Controls Division of NASA Glenn Research Center (GRC) have developed in-house a high-temperature, electronic packaging technology for operation up to 500 degrees Celsius. The Sensors and Electronic Technology Branch of GRC is seeking potential industry partners for cooperative application, development and commercialization of this technology for high-temperature electronics, sensors and MEMS. This advanced packaging technology extends the maximum operation temperature of packaging systems to 500 degrees Celsius, which, though significantly higher than the high-temperature limit of the packaging technology currently available on the market, is necessary for packaging for high-temperature electronics and devices such as silicon carbide-based (SiC) electronics for signal processing and communication; high-temperature electronic sensors for gas, chemical and emission sensing, as well as for fire and leak detection; and harsh environment-operable microsystems for control and actuation.

Commercialization of this packaging technology will expedite the infusion of high-temperature electronic sensors and devices into space, aeronautic and civil applications. Various high-temperature SiC electronic devices and sensors have recently been demonstrated to be operable at high temperatures, but only in the probe station environment, because the essential packaging technology suitable for high-temperature operation (500 degrees Celsius and above) has not been commercially available. Therefore, high-temperature packaging technology is an immediate need for in situ characterization and testing and commercialization of SiC-based high-temperature sensors, electronics and microsystems.

All the materials and processes for basic packaging components are innovative for high-temperature and harsh environment operation.

The prototype electronic package survived a soak test at 500 degrees Celsius in air. Packaging components tested include internal wire and wire bonds, external lead bonds and SiC (diode) chip die-attach. One of the test loops was composed of printed wire, wire bonds and lead bonds subjected to a DC current load at 500 degrees Celsius. As desired, the electrical resistances of the test loops (of thick-film printed wires, wire bond and lead bonds) soaked at 500 degrees Celsius with or without current load were low and very stable. Also as expected, the electrical isolation impedance between printed wires that were not electrically jointed by a wire bond remained high during and after the 500 degree Celsius soak test. The characterization of the attached SiC die (diode) showed low resistance of backside electrical contact through die-attach at both room temperature and 500 degrees Celsius. This packaging research effort is currently supported by GRC's Glennan Microsystems Initiative (GMI) and the NASA Electronic Parts and Packaging (NEPP) Program.

For more information, contact Dr. Jih-Fen Lei 216/433-6328 *Jih-Fen.Lei@grc.nasa.gov* Please mention you read about it in *Innovation*.

Low-Cost Brushless DC Motor Rate Sensor

NASA Marshall Space Flight Center is seeking commercial partners to license or jointly develop new brushless DC motor rate sensor technology that offers a promising alternative to brush tachometers, resolvers, encoders and other rotation sensors. This direction-sensitive, reliable, low-cost device is ideal for numerous commercial applications. The device is long-lasting, extremely reliable and inexpensive, with a simple design and quiet operation. Potential commercial applications include use in antilock brake systems, industrial robotics, medical and other scanning devices, power generators and navigation systems.

The sensor addresses the drawbacks associated with other rotation sensor technologies. The mechanical brushes on brush-type tachometers produce electrical arcing and wear out relatively quickly, requiring that the devices be replaced. Although prior technology using brushless DC motors/tachometers addresses this issue, most alternatives must be used in conjunction with position sensors and require that wires be added to excite the position sensor. Resolver-developed rate sensors also require wires for an excitation signal. Additionally, they usually require differentiation, which is quite noisy, to produce rate information. Finally, encoder-developed rate sensors' accuracy degrades at low rates because of the discrete nature of encoder outputs.

NASA's technology is a brushless, direction-sensitive, motor-based rate sensor that produces a DC output that is proportional to the rotation rate of a shaft. This new device is inherently linear and produces accurate rotation rate signals. The instrument is a stand-alone sensor, requiring neither electrical excitation nor an additional position sensor. Furthermore, this direction-sensitive device has a simple design that requires no mechanical brushes.

A patent application has been filed for this technology, and development and testing are continuing. NASA invites commercial companies to consider licensing or jointly developing this technology. Opportunities exist for nonexclusive and exclusive field-of-use licensing.

For more information, contact Rhonda Thompson of NASA Marshall Space Flight Center's Technology Transfer Office, 256/544-4329, *rhonda.c.thompson@msfc.nasa.gov* Please mention you read about it in *Innovation*.

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NASA Field Centers

Ames Research Center
Selected technological strengths are Information Technologies, Aerospace Systems, Autonomous Systems for Space Flight, Computational Fluid Dynamics and Aviation Operations.

Carolina Blake
Ames Research Center
Moffett Field, California 94035-1000
650/604-1754
cblake@mail.arc.nasa.gov

Dryden Flight Research Center
Selected technological strengths are Aerodynamics, Aeronautics Flight Testing, Aeropropulsion, Flight Systems, Thermal Testing and Integrated Systems Test and Validation.

Jenny Baer-Riedhart
Dryden Flight Research Center
Edwards, California 93523-0273
661/276-3689
jenny.baer-riedhart@mail.dfrc.nasa.gov

Glenn Research Center
Selected technological strengths are Aeropropulsion, Communications, Energy Technology and High Temperature Materials Research, Microgravity Science and Technology and Instrumentation Control Systems.

Larry Viterna
Glenn Research Center
Cleveland, Ohio 44135
216/433-3484
Larry.A.Viterna@grc.nasa.gov

Goddard Space Flight Center
Selected technological strengths are Earth and Planetary Science Missions, LIDAR, Cryogenic Systems, Tracking, Telemetry, Command, Optics and Sensors/Detectors.

George Alcorn
Goddard Space Flight Center
Greenbelt, Maryland 20771
301/286-5810
george.e.alcorn.1@gsfc.nasa.gov

Jet Propulsion Laboratory
Selected technological strengths are Deep and Near Space Mission Engineering and Operations, Microspacecraft, Space Communications, Remote and In-Situ Sensing, Microdevices, Robotics, and Autonomous Systems.

Merle McKenzie
Jet Propulsion Laboratory
Pasadena, California 91109
818/354-2577
merle.mckenzie@jpl.nasa.gov

Johnson Space Center
Selected technological strengths are Life Sciences/Biomedical, Spacecraft Systems, Information Systems, Robotic and Human Space Flight Operations.

Charlene Gilbert (Act)
Johnson Space Center
Houston, Texas 77058
281/483-0474
charlene.e.gilbert@jsc.nasa.gov

Kennedy Space Center
Selected technological strengths are Emissions and Contamination Monitoring, Sensors, Corrosion Protection and Biosciences.

Jim Aliberti
Kennedy Space Center
Kennedy Space Center,
Florida 32899
321/867-6224
jim.aliberti-1@kmail.ksc.nasa.gov

Langley Research Center
Selected technological strengths are Aerodynamics, Flight Systems, Materials, Structures, Sensors, Measurements and Information Sciences.

Sam Morello
Langley Research Center
Hampton, Virginia 23681-0001
757/864-6005
s.a.morello@larc.nasa.gov

Marshall Space Flight Center
Selected technological strengths are Materials, Manufacturing, Nondestructive Evaluation, Biotechnology, Space Propulsion, Controls and Dynamics, Structures and Microgravity Processing.

Vernotto McMillan (Act)
Marshall Space Flight Center
Huntsville, Alabama 35812
256/544-2615
vernetto.mcmillan@msfc.nasa.gov

Stennis Space Center
Selected technological strengths are Propulsion Systems, Test/Monitoring, Remote Sensing and Nonintrusive Instrumentation.

Kirk Sharp
Stennis Space Center
Stennis Space Center, Mississippi
39529-6000
228/688-1914
kirk.sharp@ssc.nasa.gov

NASA's Business Facilitators

NASA has established several organizations whose objectives are to establish joint-sponsored research agreements and incubate small start-up companies with significant business promise.

Bill Musgrave
Ames Technology Commercialization Center
San Jose, CA
408/557-6820

Greg Hinkebein
Mississippi Enterprise for Technology
Stennis Space Center, MS
228/688-3144

Wayne P. Zeman
Lewis Incubator for Technology
Cleveland, OH
216/586-3888, 216/229-9445

David Kershaw
Florida/NASA Business Incubation Center
Titusville, FL
321/267-5601

Celeste Moore
University of Houston/NASA Technology Center
Houston, TX
713/743-0451

Joanne Randolph
Business Technology Development Center
Huntsville, AL
256/704-6000, ext. 202

Richard C. (Michael) Lewin
Department of Business and Economic Development
Greenbelt, MD
800/541-8549

Julie A. Holland
NASA Commercialization Center/California State Polytechnic University
Pomona, CA
909/869-4477

Martin Kaszubowski
Hampton Roads Technology Incubator
Hampton, VA
757/865-2140

Ann Lansinger
Merger Technology Center NASA Business Incubator
Baltimore, MD
410/327-9150

Small Business Programs

Carl Ray
NASA Headquarters
Small Business Innovation Research Program (SBIR/STTR)
202/358-4652
cray@hq. nasa.gov

Paul Mexcur
Goddard Space Flight Center
Small Business Technology Transfer (SBIR/STTR)
301/286-8888
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NASA-Sponsored Commercial Technology Organizations

These organizations were established to provide rapid access to NASA and other federal R&D agencies and foster collaboration between public and private sector organizations. They also can direct you to the appropriate point of contact within the Federal Laboratory Consortium. To reach the RTTC nearest you, call 800/642-2872.

Ken Dozier
Far West Technology Transfer Center
University of Southern California
Los Angeles, CA 90007
213/743-2353

Dr. William Gasko
Center for Technology Commercialization
Westborough, MA 01581
508/870-0042

David Bridges
Economic Development Institute
Georgia Institute of Technology
Atlanta, GA 30332
404/894-6786

Gary F. Sera
Mid-Continent Technology Transfer Center
Texas A&M University
College Station, TX 77840
409/845-8762

Charlie Blankenship
Technology Commercialization Center, Inc.
Newport News, VA 23606
757/269-0025

Pierrette Woodford
Great Lakes Industrial Technology Center
Battelle Memorial Institute
Cleveland, OH 44070
440/734-0094

Joseph P. Allen
National Technology Transfer Center
Wheeling Jesuit University
Wheeling, WV 26003
800/678-6882

Dan Winfield
Research Triangle Institute Technology Applications Team
Research Triangle Park, NC 27709
919/541-6431

NASA ONLINE

Go to the **NASA Commercial Technology Network (NCTN)** on the World Wide Web at ***http://nctn.hq.nasa.gov*** to search NASA technology resources, find commercialization opportunities and learn about NASA's national network of programs, organizations and services dedicated to technology transfer and commercialization.

Events

NASA Glenn Research Center recently opened an ***Acoustical Testing Laboratory (ATL)*** to support the low-noise design of microgravity space flight hardware. The lab utilizes an acoustical data acquisition system that will be used to perform acoustic emission and sound power level testing. Removable floor wedges will allow the test chamber to operate in either a hemianechoic (semi-echo-free) or anechoic (echo-free) configuration, depending on the size of the test article and the specific test being conducted. For more information, please call Beth Cooper at 216/433-3950.

NASA Goddard Space Flight Center Greenbelt, Maryland, will be presenting its third ***Technology Showcase*** June 14 and 15, 2001, with an open house at Goddard held June 16. The Technology Showcase will feature award-winning technologies, interactive exhibits and forums on working with NASA and Earth and Space Sciences. For more information and to register online, visit the Web site at *http://techshowcase.gsfc.nasa.gov*

The 3rd Annual National Institutes of Health (NIH) SBIR/STTR Conference will be held July 2 and 3, 2001 in Bethesda, Maryland. The theme of the conference is "Small Businesses and NIH: Key Partners in Health Research." Program highlights include the latest changes in the SBIR/STTR program guidelines; dedicated one-on-one sessions with NIH staff; application preparation tips from successful awardees; mock study section review of SBIR applications; doing business with NIH; mining the NIH Web site; university partnerships and technology transfer opportunities; and tools for forming successful partnerships and alliances. For more information or to register visit *http://www.ncifcrf.gov/fcrdc/conf/sbir/index.html*

The NASA Commercial Technology Training Subteam is sponsoring its first ***Commercial Technology Office (CTO) Workshop*** June 26-28, 2001 in St. Louis, Missouri. The workshop is targeted to internal commercial technology office personnel and their contractors to participate in professional development and strategic planning sessions for the future of the agency's commercialization program. For more information, visit the CTO workshop Web site at *http://training.nttc.edu/ctowork/*

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Space Administration

Office of Aerospace Technology
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